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B. Cox, G. Hale, P. O. Mazur, R. L. Wagner, and D. E. Wagoner
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

and

H. Areti, S. Conetti, P. Lebrun, and T. Ryan
McGill University, Montreal, PQ, H3A 2T8, Canada

and

J. E. Brau and R. A. Gearhart
Stanford Linear Accelerator Center, Stanford, California 94305

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B. Cox, G. Hale, P.O. Mazur, R.L. Wagner, D.E. Wagoner
Fermi National Accelerator Laboratory
P.O. Box 500
Batavia, Illinois 60510

H. Areti, S. Conetti, P. Lebrun, T. Ryan
McGill University
3600 University Street
Montreal, PQ, H3A 2T8, Canada

J.E. Brau,[†] R.A. Gearhart
Stanford Linear Accelerator Center
P.O. Box 4349
Stanford, California 94305

Summary

We have measured the response of an electromagnetic shower counter constructed from the new scintillation glass (SCG1-C, Ohara Optical Glass, Inc.) to positrons in the energy range 2 to 17.5 GeV. We have measured the energy resolution of this 18.4 radiation length detector plus its attendant SF5 lead glass shower counter array to be $\sigma/E = (1.64 \pm 0.14)\% + (1.13 \pm 0.33)\%/\sqrt{E}$ with the constant term dominated by variations in the conversion point of the positron and shower leakage. We found this counter to be linear over the energy range examined. We have also measured the light output of the SCG1-C counter relative to light output of the SF5 lead glass guard blocks using 17.5 GeV positrons. We find that the SCG1-C counter produces 5.10 ± 0.30 more light at the phototube than the SF5 lead glass counters.

[†]Present address: Department of Astronomy and Physics, Univ. of Tennessee, Knoxville, Tennessee 37916.

Introduction

A new type of high density glass (SCG1-C from Ohara Optical Glass, Inc.) has recently been developed^{1,2} which can be used in electromagnetic shower counters for high energy physics. This glass differs in two major ways from the various types of lead glasses which have been used for over a decade in high energy physics in two major ways. This glass has barium oxide rather than lead oxide as the high Z material and contains Ce_2O_3 which acts both as a scintillator and a wavelength shifter for Cerenkov radiation. The blue and near ultraviolet Cerenkov light is absorbed and reemitted at longer wavelengths which survive absorption by the glass. The observed net gain, relative to that possible with lead glass, in the number of photons which reach the photomultiplier results in an improvement in the part of the energy resolution due to photon statistics.

This scintillation glass, along with earlier versions, has been tested³⁻⁶ with low energy photons and electrons (< 300 MeV). We have constructed an electromagnetic shower counter which is suitable for high energy shower measurements from this new glass and have tested it using high energy (2 to 17.5 GeV) positrons at the Stanford Linear Accelerator Center (SLAC).

Beam

This test was performed using the positron test beam 19 in the B end station at SLAC. This positron beam had a momentum bite, $\Delta p/p$ (FWHM) = 0.25%, and a small phase space with 90% of the beam particles contained within a beam spot of radius 1 mm. The contamination of this beam by pions and muons was less than 10^{-5} over the entire momentum range. The momentum of this beam was

tuneable from 2 to 17.5 GeV/c. We typically operated the beam at 10 pulses per second with an average of less than 0.3 positrons per 1.6 μ s pulse. Beam pulses with two or more positrons were tagged and later rejected in the off-line analysis.

Experimental Apparatus

The arrangement of shower counters used for this test is shown in Fig. 1. The array consisted of a central counter composed of the scintillation glass, SCG1-C, surrounded by eight SF5 lead glass guard counters to capture the transverse leakage of the high energy showers. The SCG1-C counter was 80 cm in length (18.4 radiation lengths) and 15 cm x 15 cm in cross section and had the composition shown in Table I.

Table I

Composition of SCG1-C Scintillator Glass²
(by weight)

BaO	43.4%
SiO ₂	42.5%
Li ₂ O	4.0%
MgO	3.3%
K ₂ O	3.3%
Al ₂ O ₃	2.0%
Ce ₂ O ₃	1.5%

The heavy compound which is the major contribution to the 4.35 cm radiation length is BaO and the scintillating, wavelength shifting component is Ce₂O₃. This particular counter, constructed from two 40 cm pieces, was viewed toward the incoming positron beam by an RCA 8055 photomultiplier. Epotek 305 epoxy was used for the glass-glass joint and for the tube-glass joint in this counter. The eight SF5 guard blocks were 45 cm in length (18.0 radiation lengths) and 15 cm x 15 cm in cross section. These counters were also viewed

end on by RCA 8055 tubes. The shorter guard blocks were positioned so that their upstream ends were 25 cm from the upstream end of the SCG1-C counter. This positioning was chosen for the maximum containment of the transverse shower leakage from the SCG1-C counter. Each of the nine counters of the array had a red LED (Monsanto MV10B) mounted on the end of the counter opposite to the phototube for purposes of gain monitoring.

Experimental Results

The pulse shape obtained from the SCG1-C counter resulting from a 17.5 GeV positron shower is shown in Fig. 2 along with the counter's response to a 40 ns pulse from a green LED (Monsanto MV5252). The time response of the RCA 8055 tube is a major contributor to the 300 ns length of these pulse shapes. We have estimated the exponential fluorescent decay time of the glass from the difference of the two pulse shapes to be approximately 70 ns. Both 400 ns and 1 μ s gates were used with a LeCroy 2249W ADC with no observed difference in the energy resolution. The measurements reported in this paper were performed with the 400 ns gate.

The calibration constants, C_i , for each element of the array were defined by $E_{ik} = C_i P_{ik}$ where E_{ik} is energy deposited and P_{ik} the observed pulse height in the i^{th} counter for the k^{th} shower. These constants were determined from a set of 4.0 GeV runs using an iterative, bootstrap technique⁷. Initially, a starting estimate was made for the calibration constant of each of the nine counters. For the i^{th} individual counter the calibration constant C_i was then determined by minimizing the chi-square

$$\chi^2 = \sum_{k=1}^N (E - \sum_{j=1}^9 C_j P_{jk})^2 \quad E = \text{beam energy}$$

with respect to C_i . The minimization leads to the formula for C_i :

$$C_i = \frac{\sum_{k=1}^N (E P_{ik} - \sum_{\substack{j=1 \\ j \neq i}}^9 C_j P_{jk} P_{ik})}{\sum_{k=1}^N P_{ik}^2}$$

Using this formula and a data sample of N showers with a 4.0 GeV beam centered in the i^{th} counter, the C_i calibration constant was calculated. This C_i then replaced the initial (or the current iteration) value for the i^{th} counter for the next iteration through the array. Using this technique, the calibration constants for the array stabilized after three iterations.

The resolution and linearity of the SCG1-C counter and its accompanying guard counter array were determined by positioning the positron beam at the center of the SCG1-C counter (to ± 1 mm) and recording a few thousand showers at energy settings of 2, 4, 10 and 17.5 GeV. Pulse height spectra for 2 and 17.5 GeV energies obtained by summing the pulse heights above pedestals in the array are shown in Fig. 3a and 3b. The majority of the energy of the showers was contained in the SCG1-C counter with only approximately 3.6% of the visible shower leaking into the guard blocks. (This fraction was nearly independent of energy.) The linearity of the array with the beam centered on the SCG1-C counter is shown in Fig. 4. We find that these data fit a straight line constrained to the origin with a χ^2 of 3.2 for 3 degrees of freedom.

The energy resolution of the test array (which is dominated by the SCG1-C counter response) is shown in Fig. 5 plotted against $1/\sqrt{E}$. These data fit the form $\sigma/E = a + b/\sqrt{E}$ with $a = 1.64\% \pm 0.14\%$ and $b = 1.13\% \pm 0.33\%$. This resolution is to be compared with the result $\sigma \sim 1.65\%/\sqrt{E}$ obtained by Bartalucci³ using 60 MeV photons and $\sigma \sim 2.5\%/\sqrt{E}$ obtained by Chiba⁶ using 20 to 120 MeV electrons. These experiments were in the energy regime in which sensitivity to a constant term was small. We have used the EGS shower Monte Carlo program⁸ to estimate various sources of contributions to the constant term. Of the 1.6% which we observe, 1.4% can be expected from the sources listed in Table II.

Table II

Estimated Contributions to the
Energy Independent Term of the SCG1-C Resolution

Conversion Point Fluctuations	1.1%
Undetected Energy Leakage Fluctuations	0.8%
Resolution of Guard Blocks for Detected Transverse Leakage	0.3%
Momentum Spread of Test Beam	0.1%
Fluctuation of Shower Across Glue Joint	0.1%

Each of these sources of the energy independent term are to the first order independent and therefore can be added in quadrature to get the 1.4% estimate of the constant term. The largest contribution comes from the differential optical attenuation of the light from positrons converting at different depths in the glass. This contribution may be minimized by an appropriate filter at the phototube to cut out the component of the light at short wavelengths which fluctuated because of differential absorption. In addition, corrections for the position of the conversion point may be applied on a shower by shower basis if the longitudinal development of the shower is sampled by use of an active converter. The second largest contribution to the constant term, the undetected energy leakage fluctuations, can be reduced by increasing the

length of the SCG1-C counter and by proper matching of the lengths of the guard counters to the central counter in order to minimize undetected transverse shower leakage.

Finally the relative light yield of the SCG1-C counter and one of the SF5 guard counters was measured. The relative gain of the phototube of the SCG1-C counter and the guard counter was determined by comparing the pulse heights from a red and green LED which were viewed by both these counters. The relative gain determined in this manner has been corrected for the different absorption of the LED light by the SF5 and SCG1-C glass. The two counters were then exposed to a 4 GeV positron beam and the resulting pulse heights adjusted for the relative gains of the tubes. The ratio of the light outputs of the SCG1-C counter to the SF5 counter determined in this way was found to be 5.10 ± 0.30 . Most of the error in this ratio originates in the mechanical reproducibility of the gain measurement which required moving the LED's from one counter to the other.

Conclusions

A counter constructed from Ohara SCG1-C scintillation glass has been tested in a high energy positron beam and has been found to have resolution ($\sigma/E = 1.64\% + 1.13\%/\sqrt{E}$) and good linearity. For comparison the resolution for lead glass measured by other experiments^{7,9} is of order $\sigma/E \sim 1\% + 4.5/\sqrt{E}$. In a complete scintillation glass detector the energy independent term can be reduced by reducing leakage and by compensation for conversion point variations. The intrinsic decay time of glass is consistent with an $\exp(-t/70 \text{ ns})$ behavior. The light from a 4 GeV shower arriving at the photomultiplier

of this counter is larger by a factor of 5.10 ± 0.30 than that for a comparable SF5 counter. We were encouraged by these results and are designing a larger scintillation glass detector for Fermilab Experiment E-705.¹⁰

Acknowledgments

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SCG1-C SCINTILLATION GLASS
TEST ARRAY

RCA 8055 PHOTOTUBES

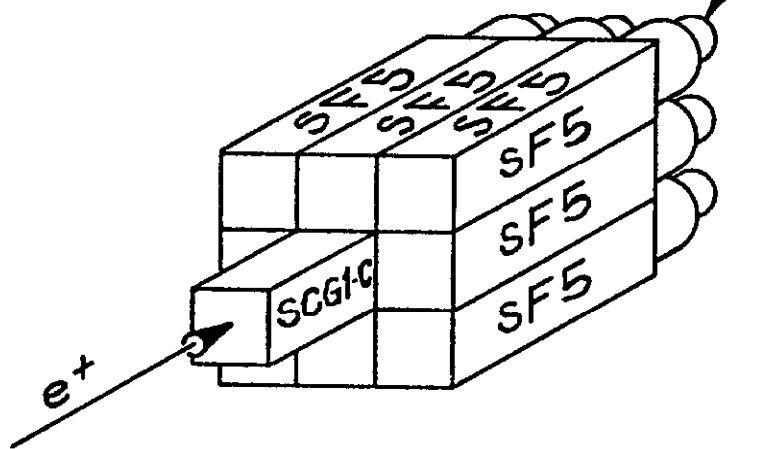
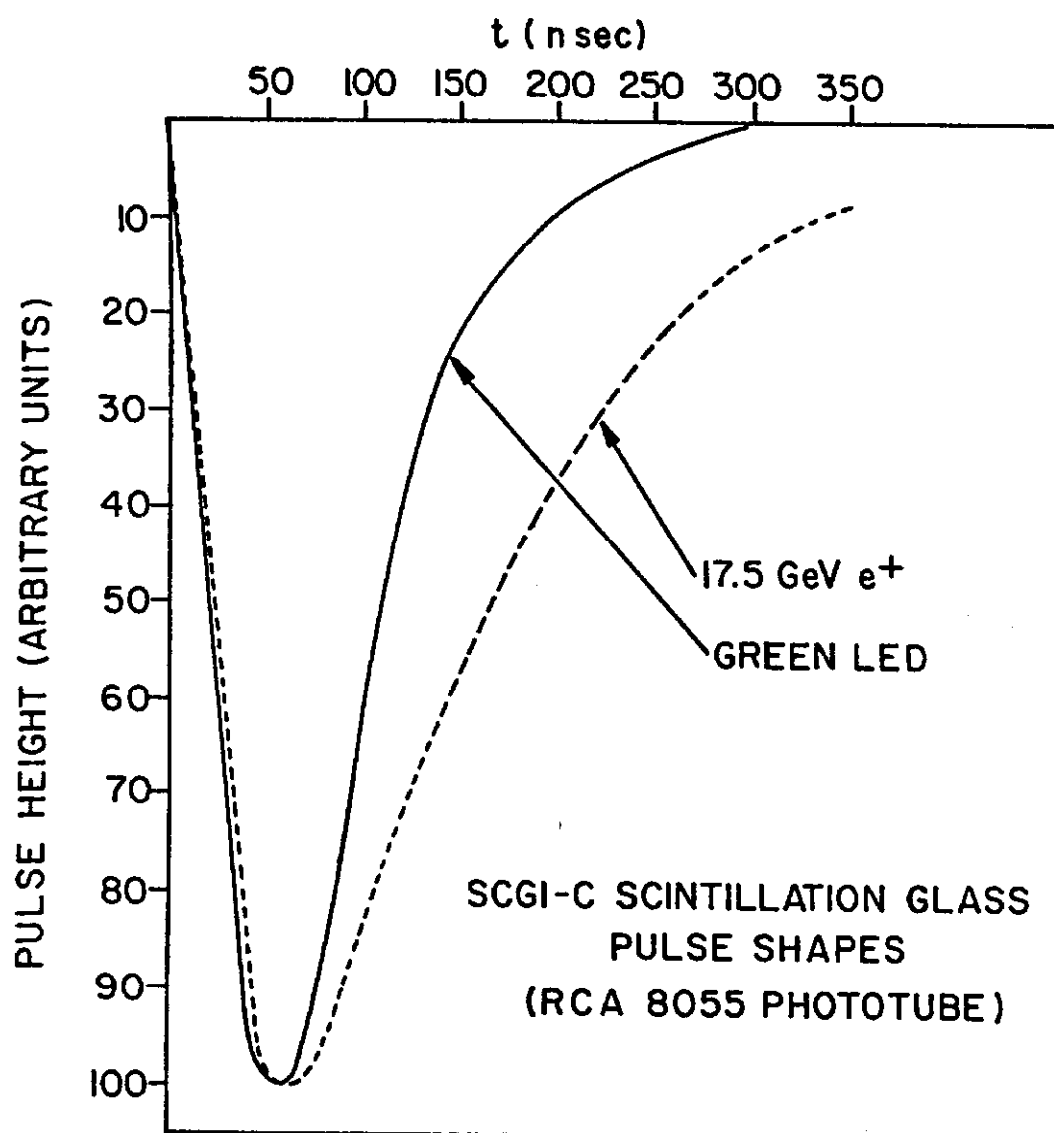
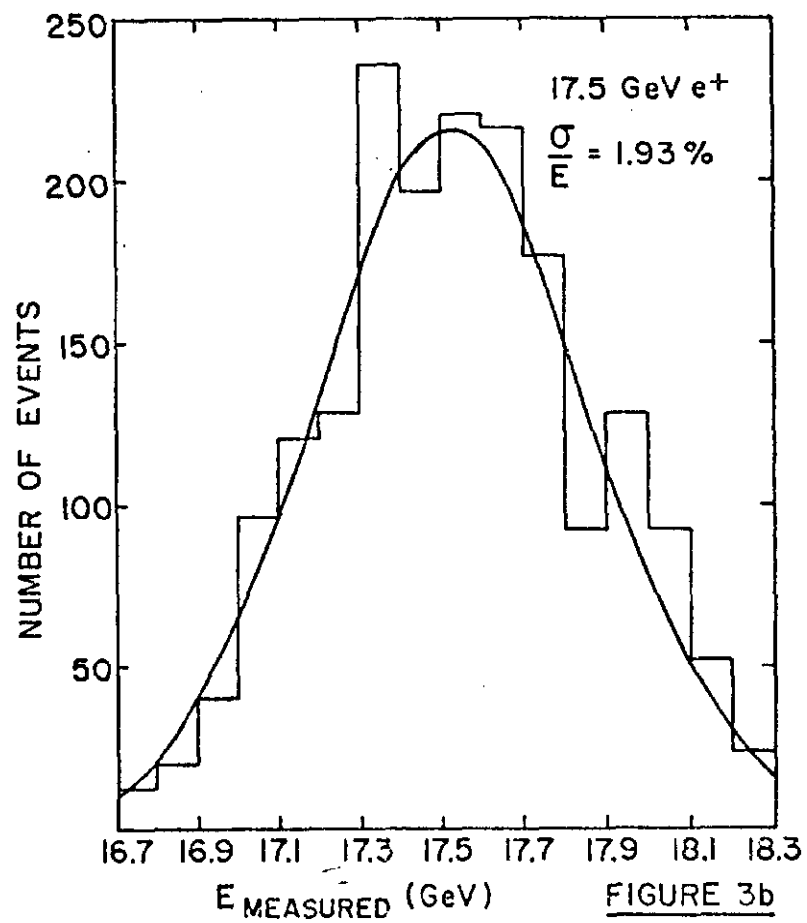
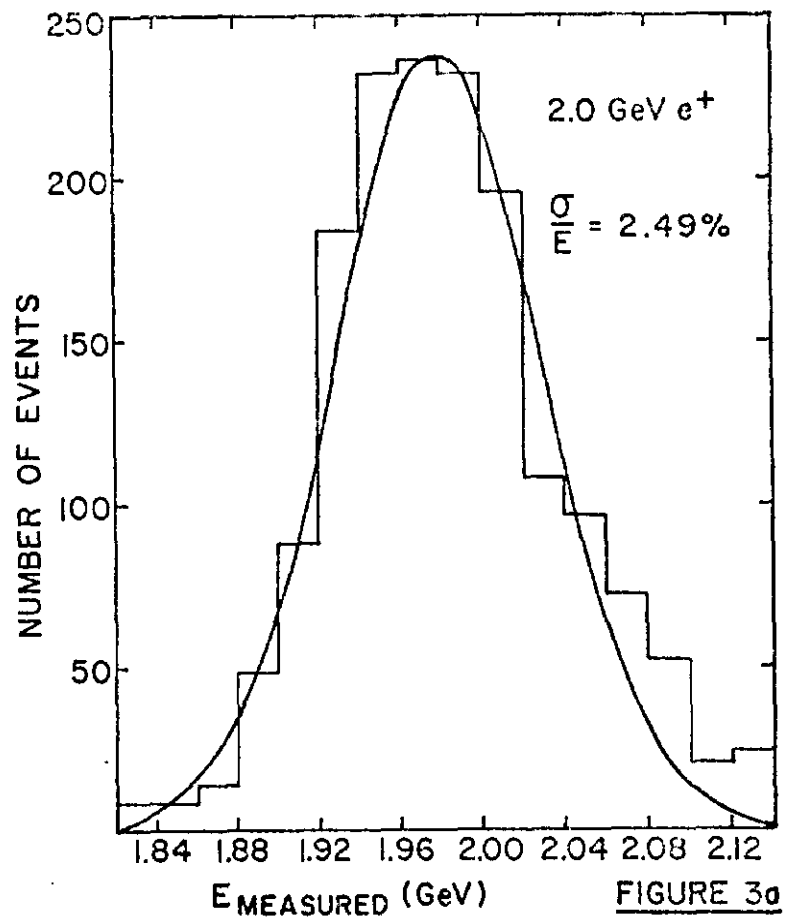
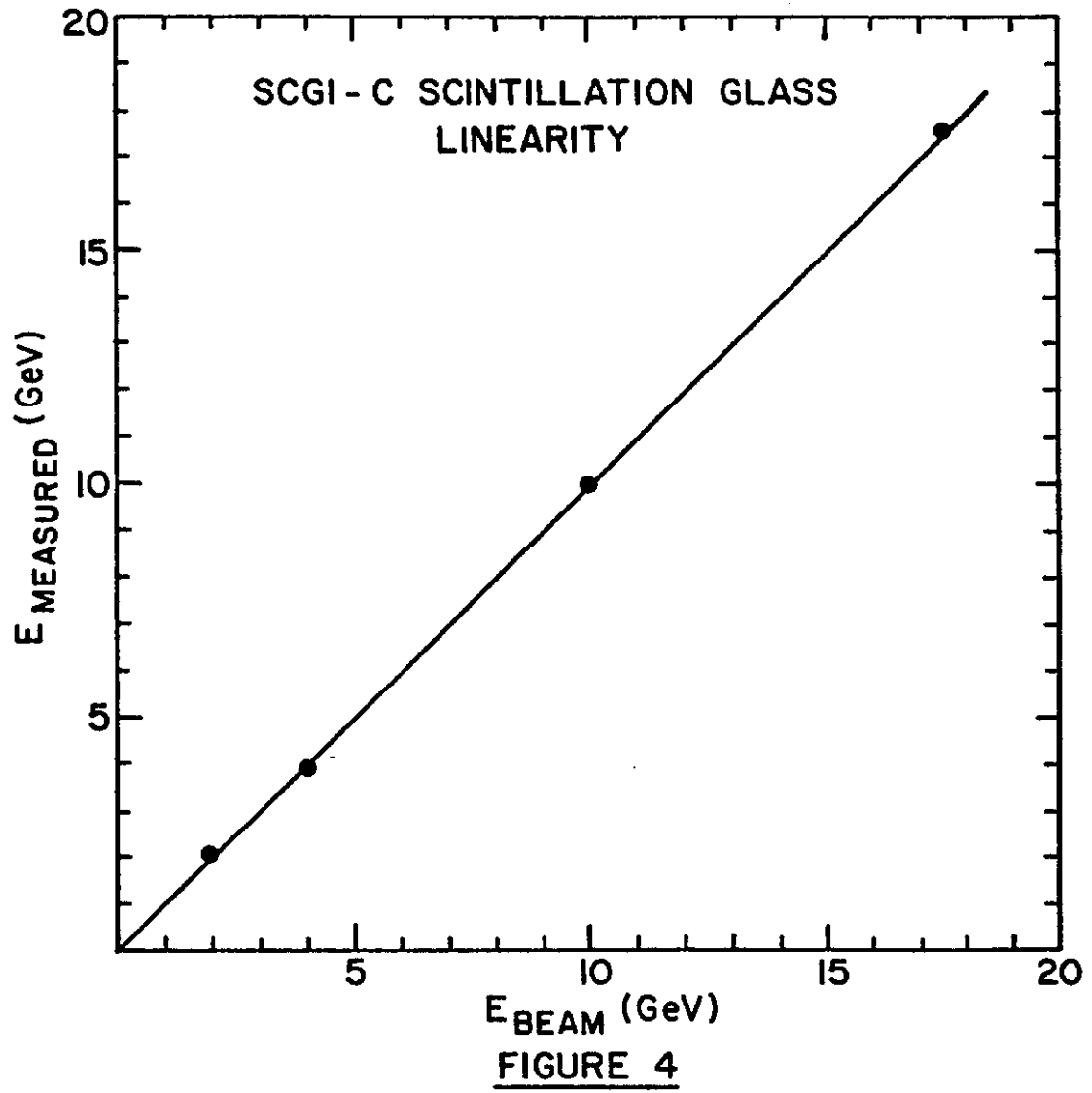


FIGURE 1

FIGURE 2





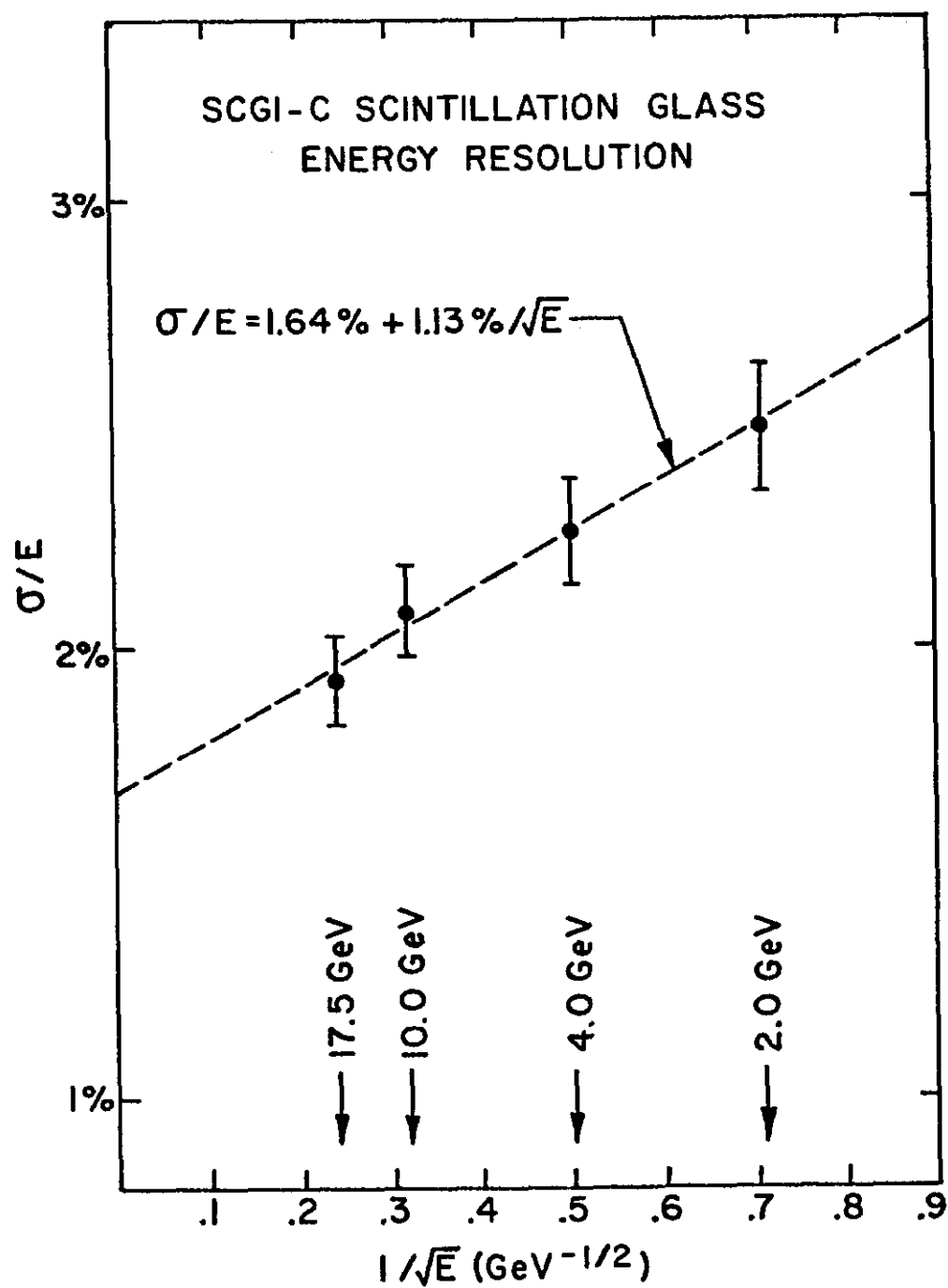


FIGURE 5